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200 Ohm Chopper Progress Update
(Chopping beam)

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PIP2 Meeting

25 July 2017

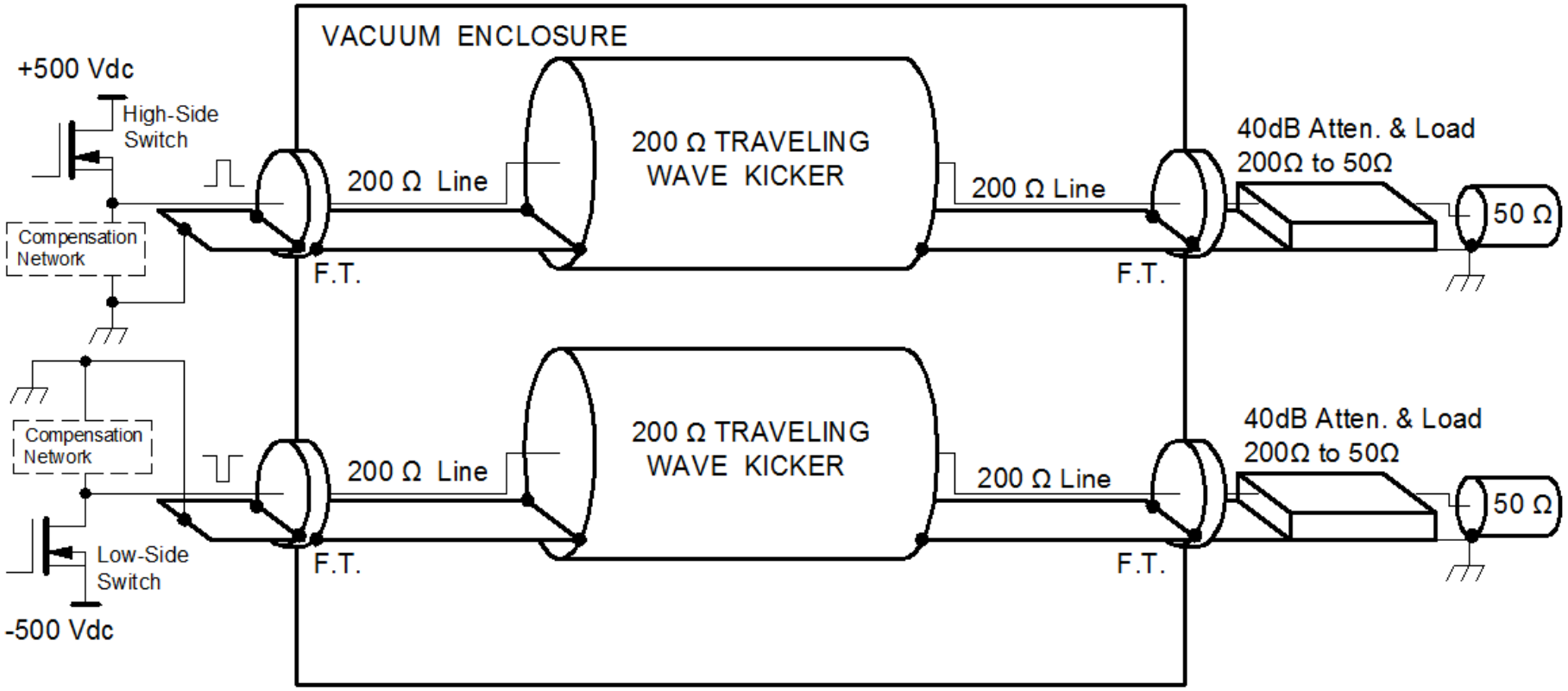
Topics

- Review of 200 Ohm Chopper as installed
- First demonstrations of chopping beam
- Installation at PIP2-IT facility
- Future roadmap

Acknowledgements

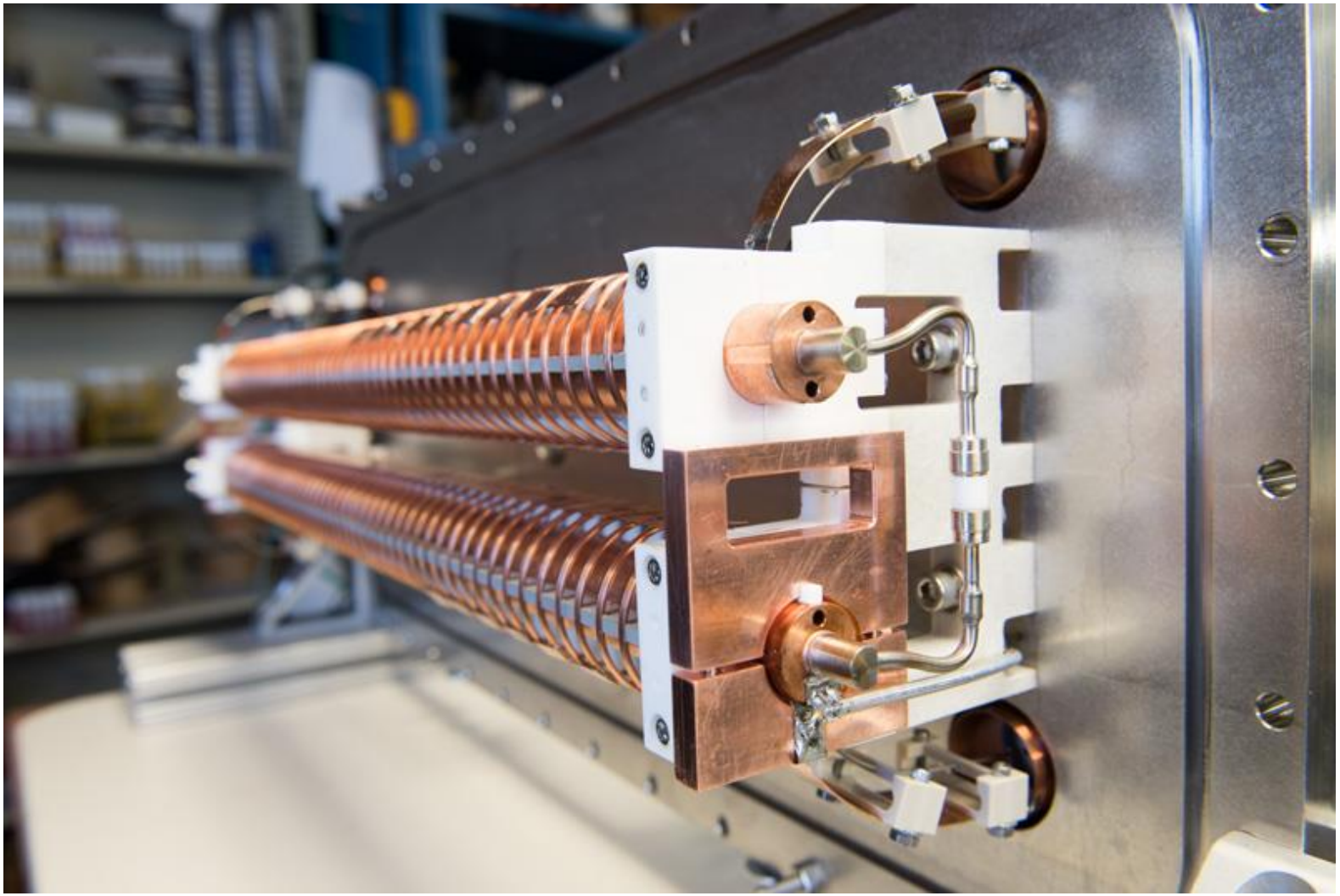
- Dan Wolff, Howie Pfeffer and now Chris Jensen
  - Initiation of my involvement, strategic and technical guidance and support
- Sasha Shemyakin
  - Persistent support while maintaining clear objectives
- Brian Chase and Milorad Popovic; Valeri Lebedev
  - Early collaboration with Brian and his discussion on considering a helical kicker structure; Brian's LLRF fast waveform generator
  - Valeri's equations used in considering electrode design for efficiency
- Alex Chen
  - Kicker mechanical design, and modeling a FET cooling option for CW
- Mohamed Hassan
  - Helical kicker modeling and analysis
- Vic Scarpine, and company, including Andrea Saewert, Brian Felenz
  - Instrumentation for measuring chopped beam characteristics
- Brian Chase, Shailesh Khole, Dheeraj Sharma, Josh Einstein
  - Beam-synchronous and arbitrary trigger generation
- Daniil Frolov
  - Valuable engineering contributions in addition to photonics expertise
- Jeff Simmons
  - Tireless assistance with assembly, testing, drafting and various technician support tasks

Chopper assembly

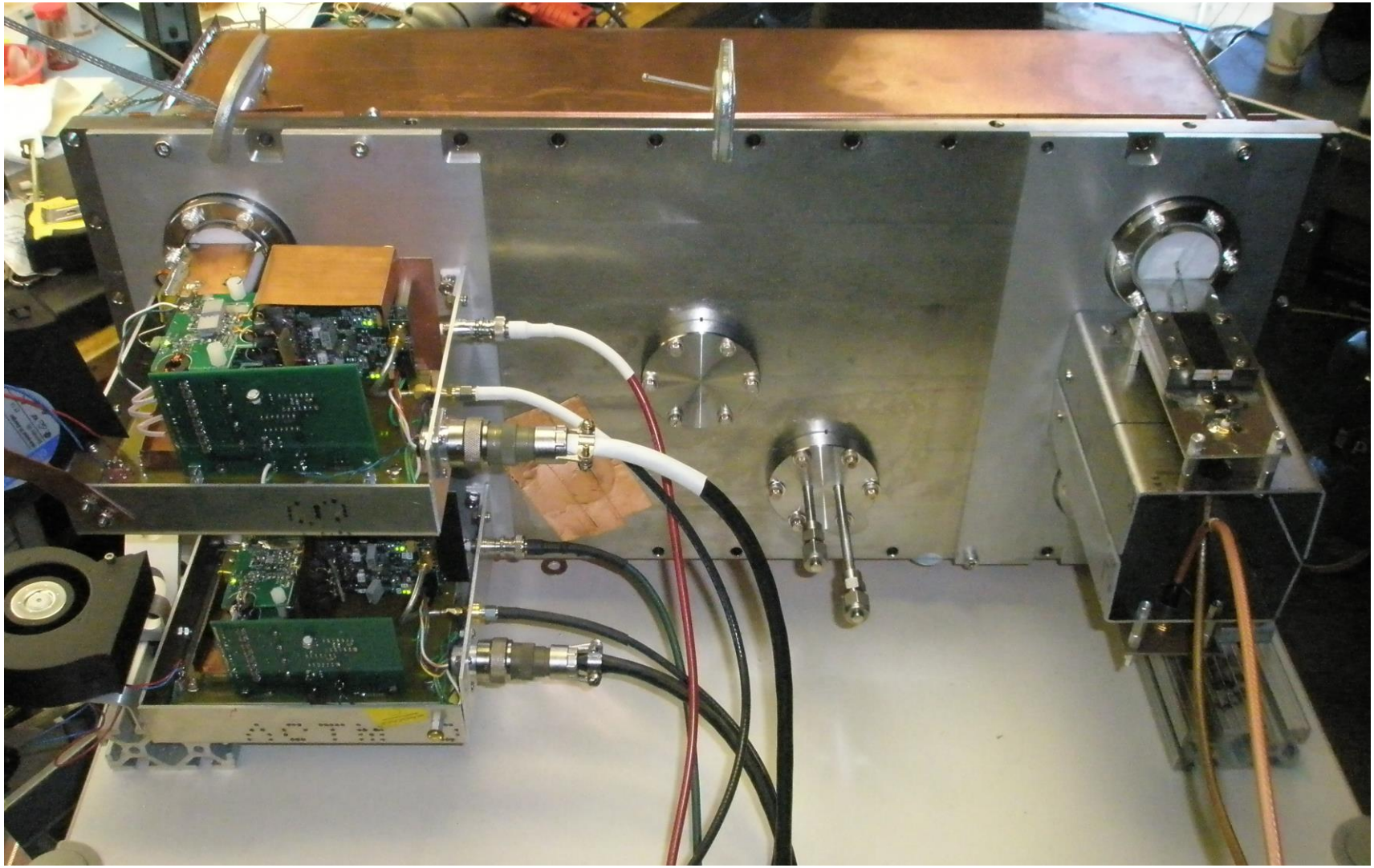


- The Chopper spec is ± 500 V, but many bench tests performed at 600 V
- The very same hardware tested and presented last December is what is now installed at PIP2-IT

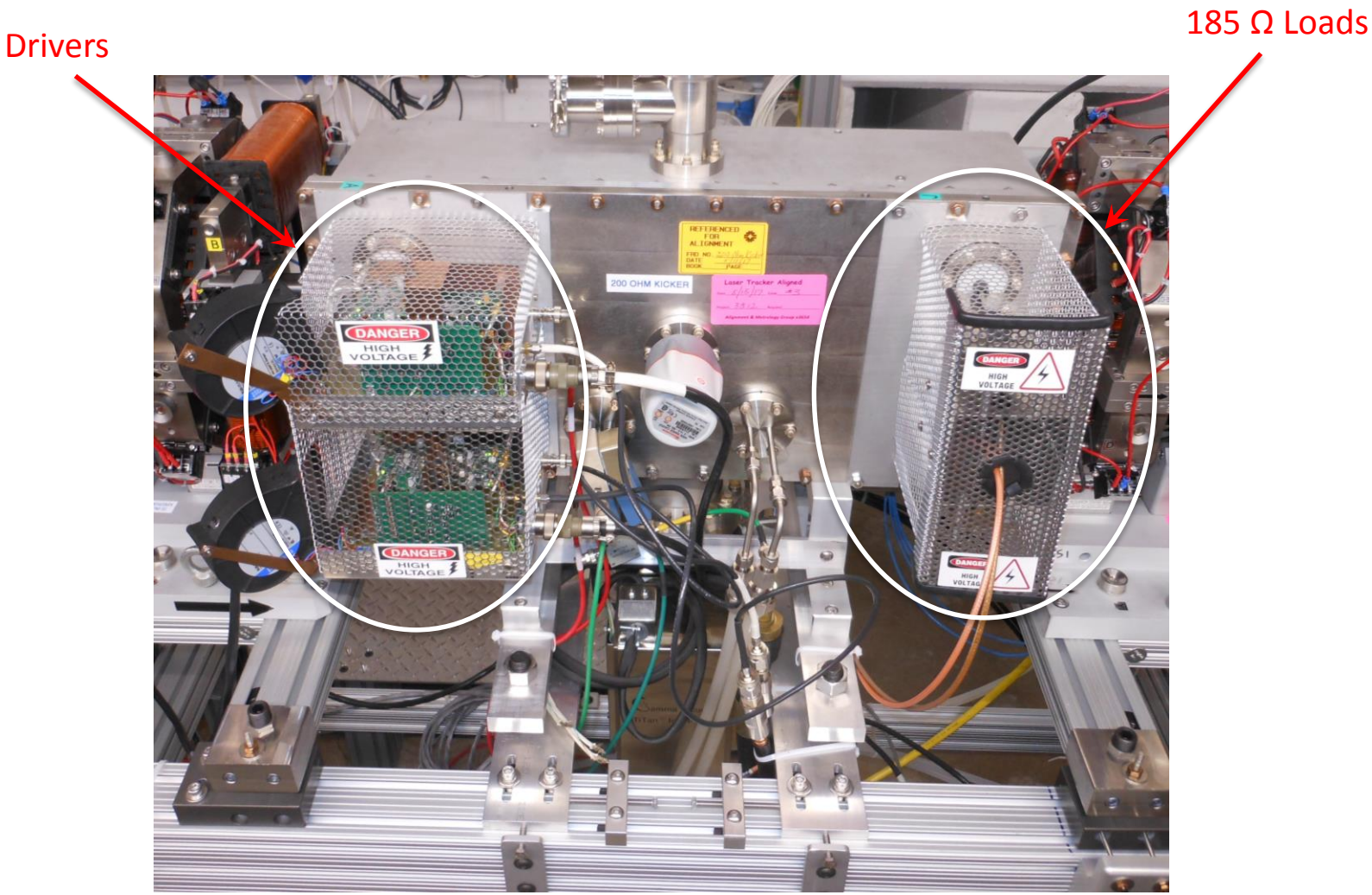
Kicker helices and upstream protection electrode



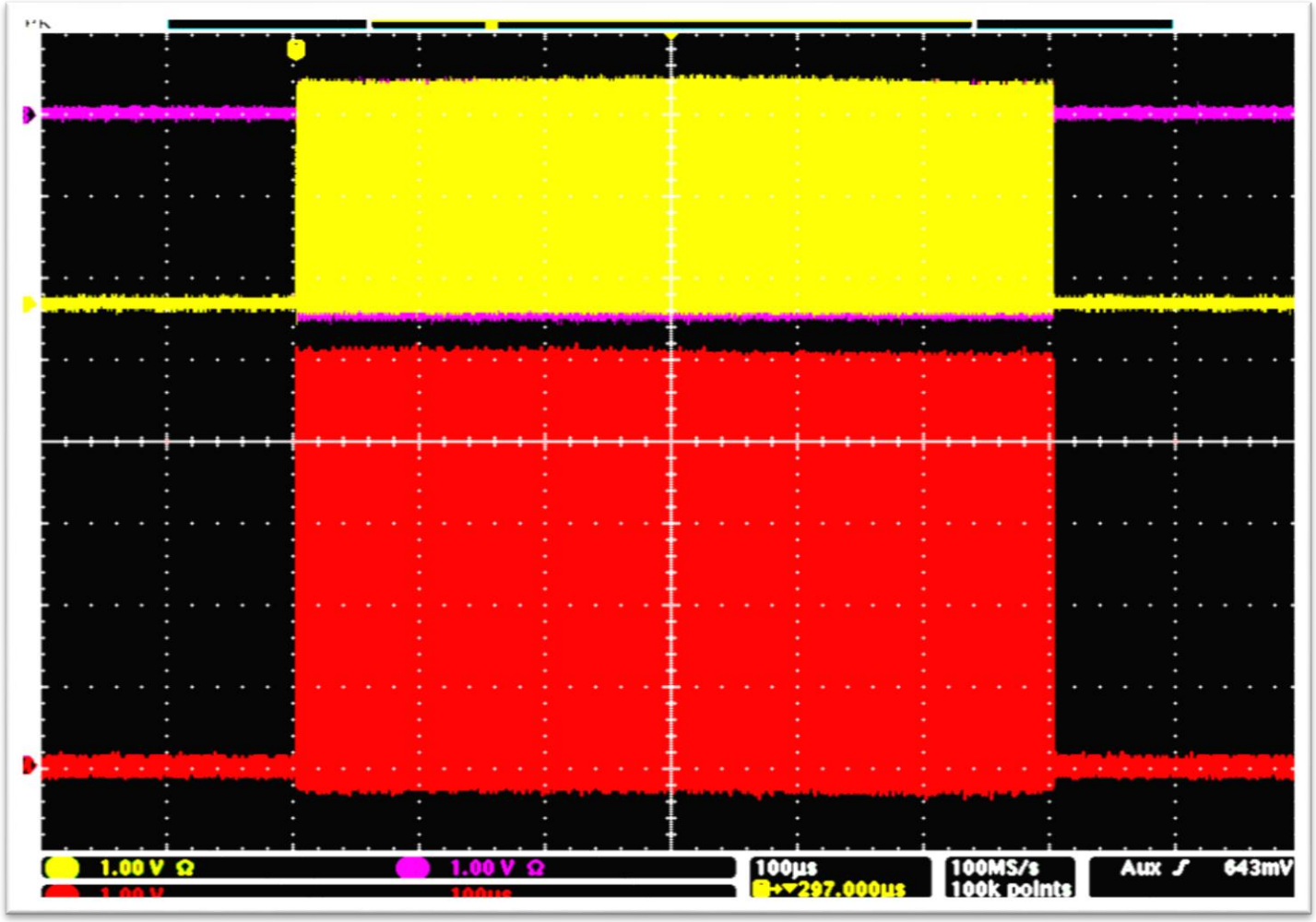
Air-side components: drivers and loads



200 Ohm Chopper Installed at PIP2-IT



Switching ±550 V PIP-2 Phase 1 (45 MHz for 600 μs @ 20 Hz)



Upper Helix

Lower Helix

Difference Voltage

Simulated beam bunches

Vertical
≈ 220 V /div

Horizontal:
100 μs /div

- 45 MHz is approximate PIP2 Phase I average switching rate requirement
- Switched at 45 MHz CW, since no arbitrary waveform generator was available

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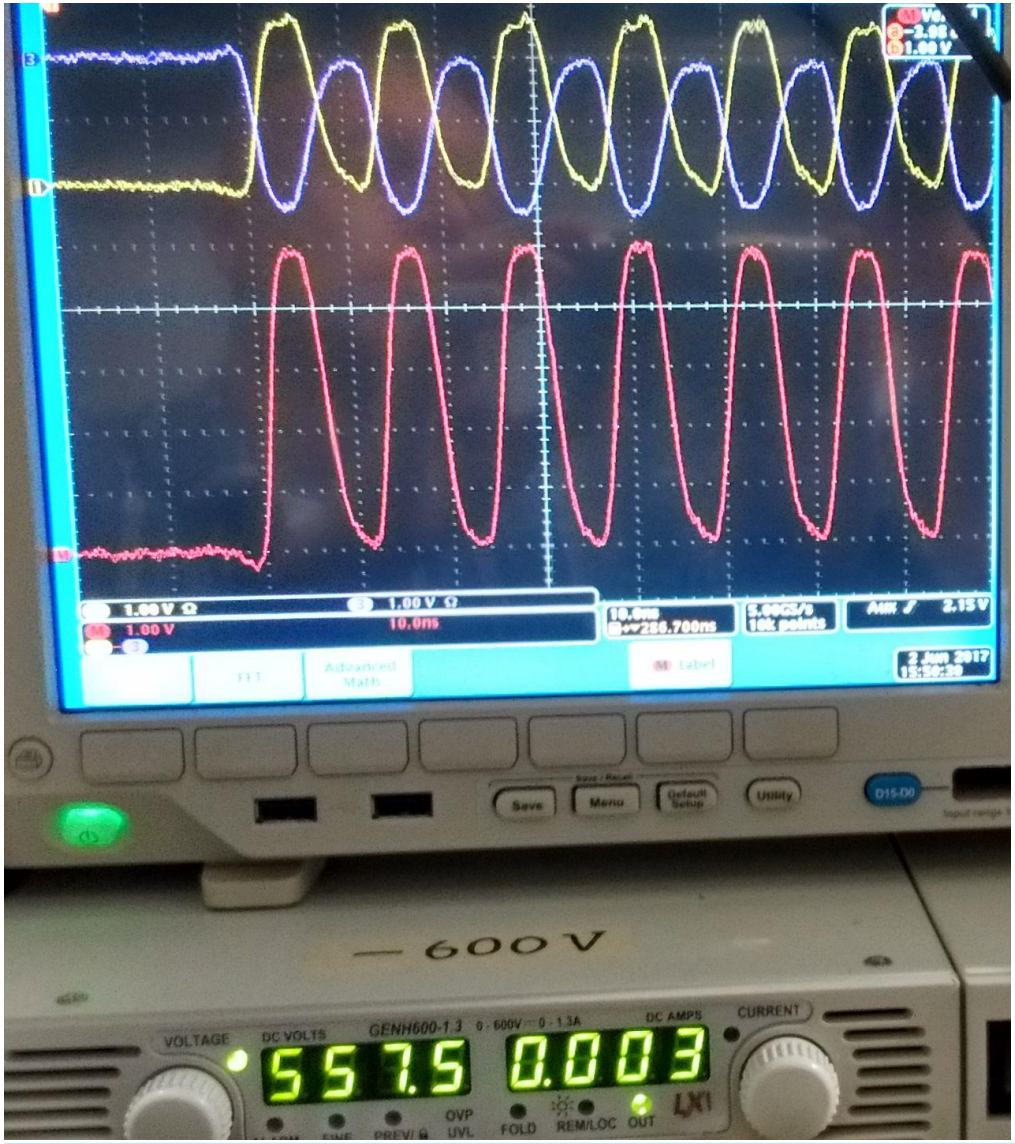
Installed chopper through-voltage signals, 81.25 MHz switching



Upper Helix

Lower Helix

Plate Difference Voltage
= 1100 V

Horizontal:
10 ns /div

Bias Voltage PS
(Volts, Amps)

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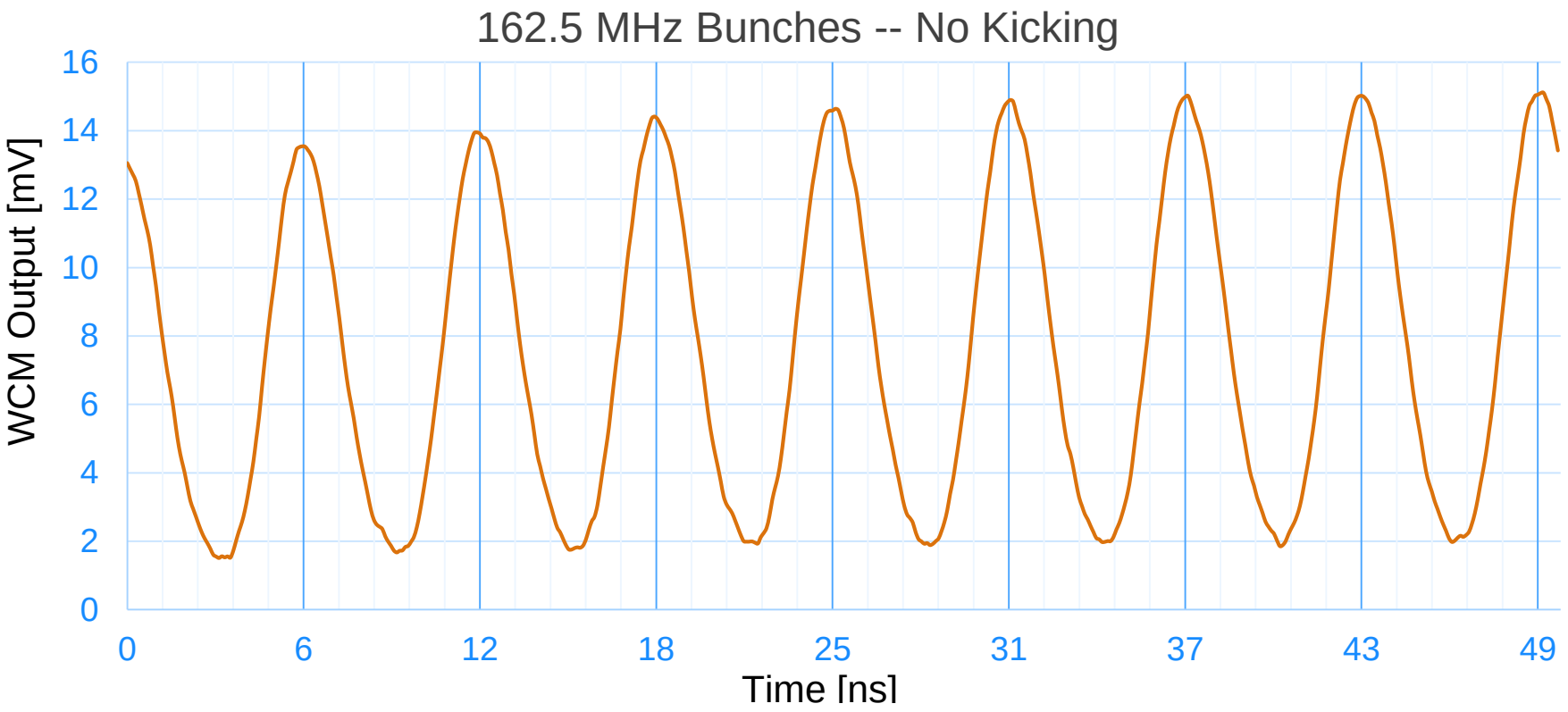
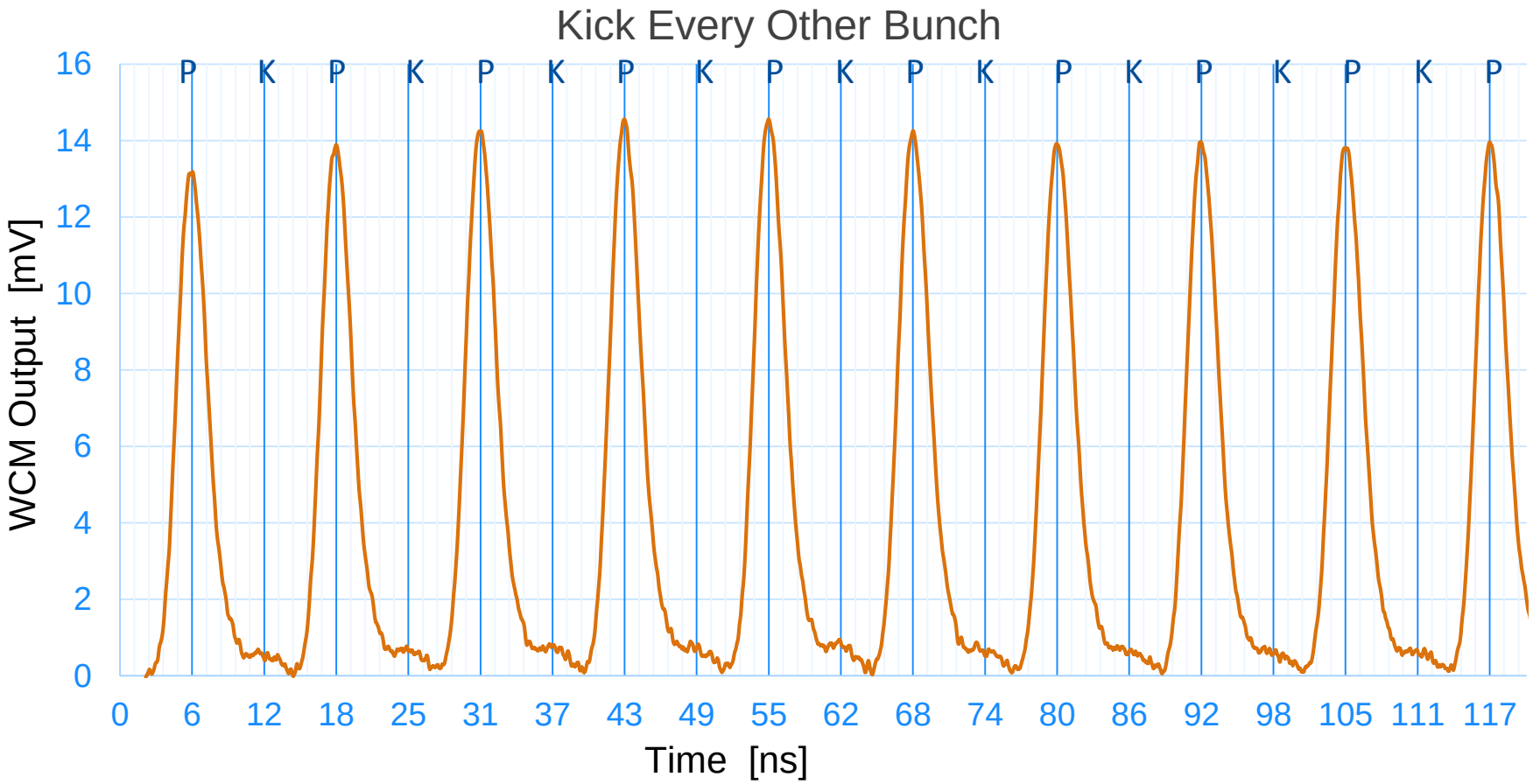
Resistive Wall Current Monitor (RWCM) signals



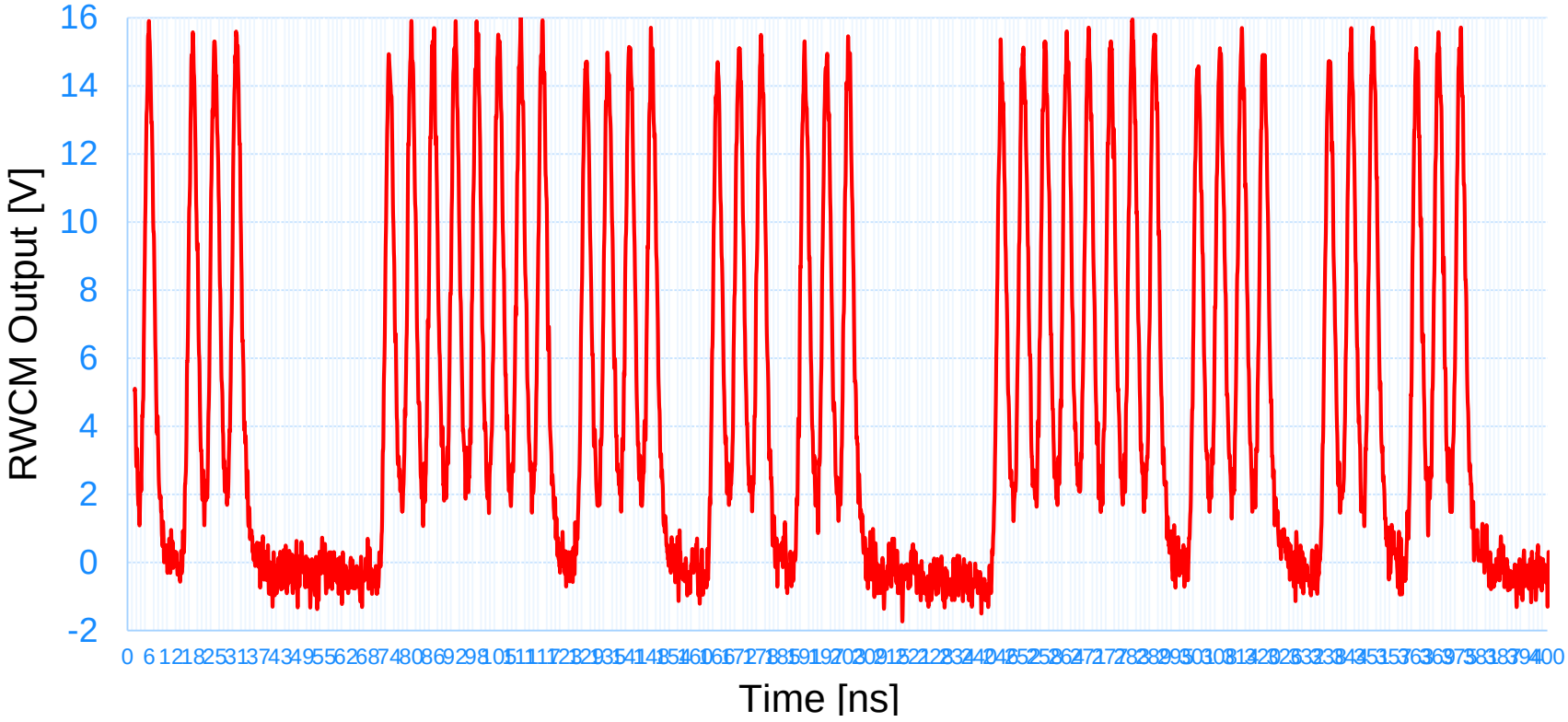
- Resistive Wall Current Monitor is intended to provide passing-beam detail
- Scope averaging is on giving low-noise appearance

Kicking bunches at 81.25 MHz (RWCM signal)



- Every other bunch is kicked out
- Bunches kicked out are scraped off and do not appear
- "K" and "P" indicate "Kicked" and "Passed" bunches, respectively

Kicking an arbitrary pattern (RWCM signal)



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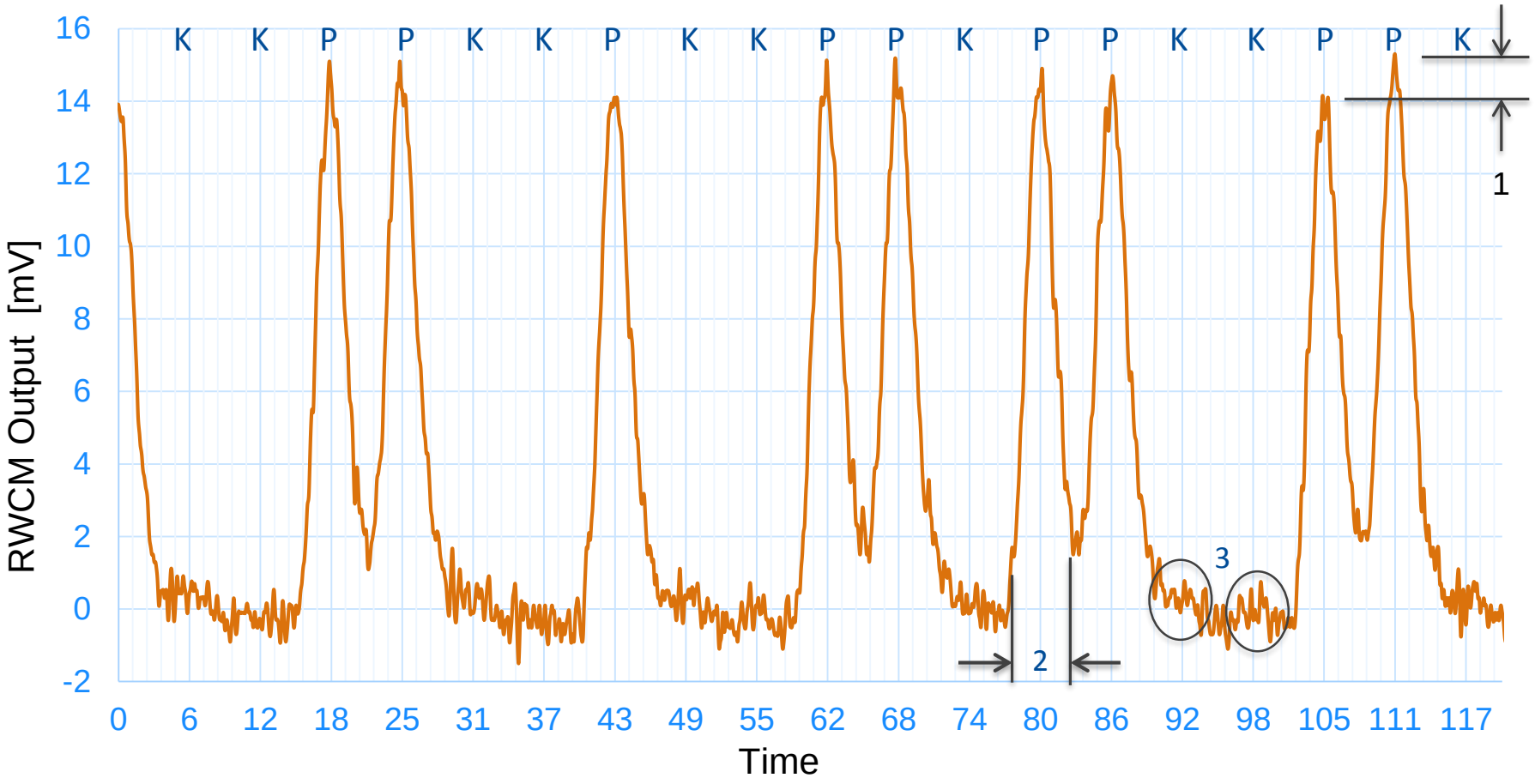
Kicking arbitrary, pseudo-PIP2 Phase 1 pattern (RWCM signal)



- Average switching rate = 46.4 MHz for 12 μs bursts at 20 Hz
- Scope averaging is off

Observations and comments

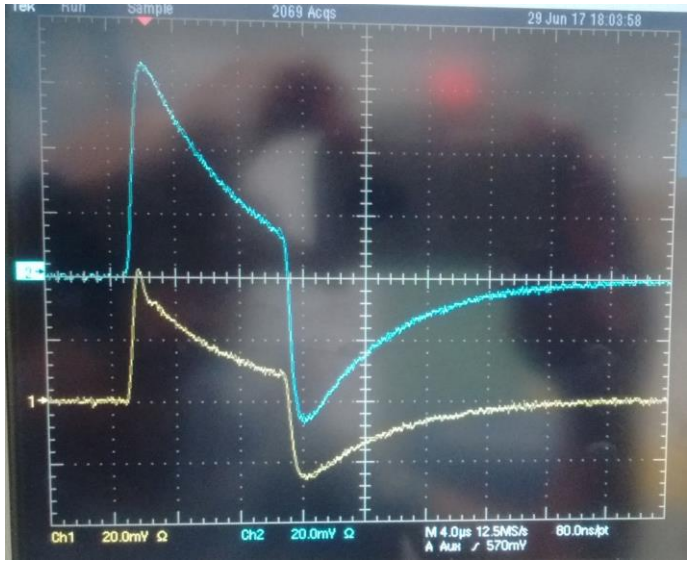
1. Beam intensity fluctuations ~11% at megahertz rages
2. RWCM signals reveal beam and instrumentation limitations
   a. E-field elongation in the RWCM due to its 2” radius
   b. ¼” Heliax cable bandwidth limitation
   c. Buncher cavity was off: bunch length is definitely longer than 1.3 ns (6σ) spec value
   d. Appearance of bunches not going to zero volts is not chopper related (see slide #10)
3. Some beam smearing: beam passing through that should be kicked out after the previous bunch allowed to pass
   a. Bunch length is definitely longer than 1.3 ns (6σ)!
   b. Cannot blame, yet, the chopper for smearing
4. Testing with tuned beam is required to determine real extinction performance

Planned protection for chopper Protection Electrodes

The scheme to protect the electrodes in **real-time** – regardless of the bunch length

- Continuously integrate the measured Protection Electrode current in the digitizer board's FPGA
  - This value is proportional to deposited energy
  - Include a lossy term having a time constant corresponding to the rate energy is dissipated
- Output a trip indication to the MPS when value hits a defined limit of 50 mA·μs
  - This value is 4.2 V ·μs scaled to the Current Monitor 50 Ω output
- Plot, below, shows switching noise of the electrode current
  - The integrated noise of the positive excursion is 0.42 V ·μs (downstream electrode)
- Conclusion: noise is not trivial for long bursts

Current Signal When Switching at 81 MHz, +/- 550 V, 12 μs Burst Duration

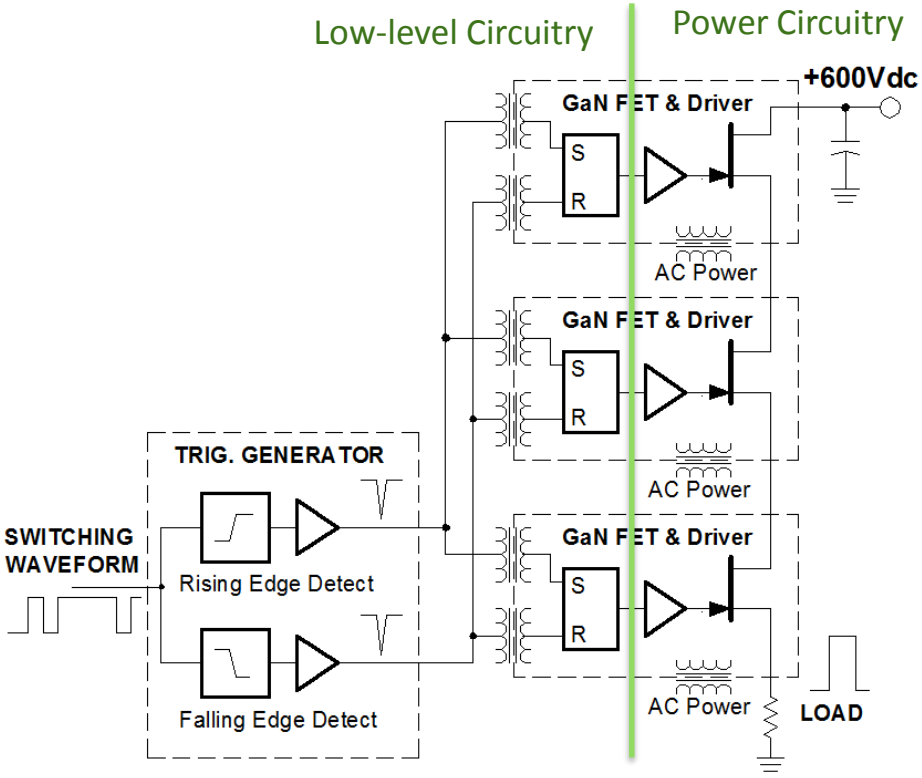


Downstream
20 mV/div

Upstream
20 mV/div

4 μs/div horizontal

Chopper driver (high-side topology shown)



- Transformers communicate Set and Reset voltage spikes that allow for creation of any arbitrary waveform
- Set-Reset latches in the driver reconstruct the kicking waveform.

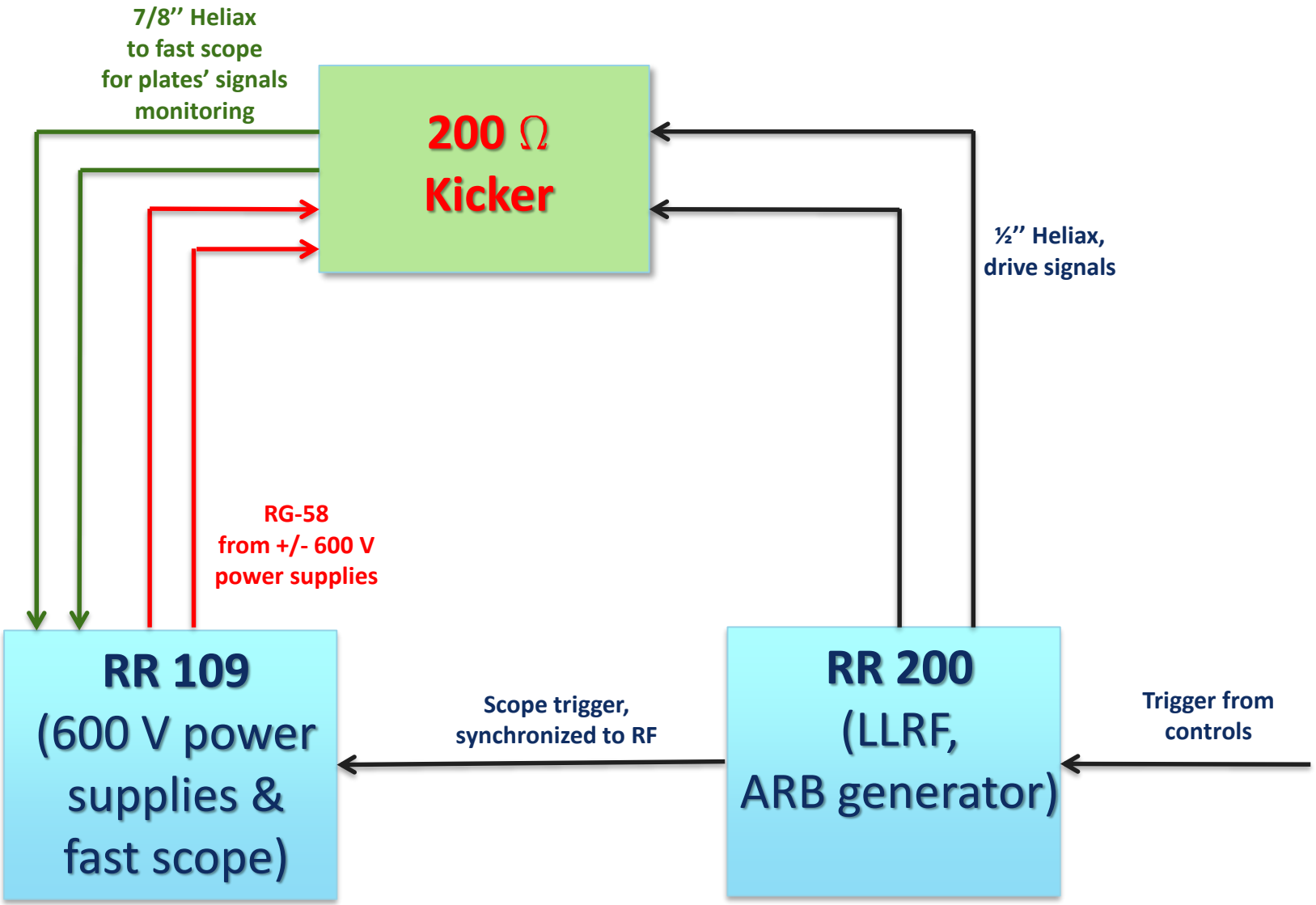
Operational status summary

- 200 Ω Chopper **demonstrated** capabilities
  - Helix and load
    - Helices' phase velocities are matched to the beam to under 0.5%
    - Voltage re-reflections are at or under 5%
    - Loads are rated for >500 W
      - Operational duty factor for PIP2-Phase 1 require no added cooling
  - Driver
    - Operates at 600 V
    - Switches 550 V at >81.25 MHz, >12 μs bursts at 20 Hz rates
    - PIP2 Phase 1 requirements
      - switching rate: 45 MHz average for 600 μs at 20 Hz intervals
      - waveforms: output arbitrary switching patterns including ones matching those required
      - FET junction temperatures rise: ~45 ºC during 600 μs bursts at 20 Hz -- which is acceptable
      - cooling requirements: only modest forced-air
- The 200 Ω Chopper appears suitable for PIP2-Phase 1

What remains to be done?

- Driver power section is acceptable
  - Speed margin: operated >90 MHz at rated voltage
- Driver issues are in the low level section
  - Driver timing does not have quite acceptable adjustability margin
  - Transformers, primarily, are the limitation
- The updated low level circuitry is almost ready to be installed at PIP2-IT
- More detailed testing with beam before October
- Demonstrate a path to CW

Present 200 Ohm Kicker interconnections



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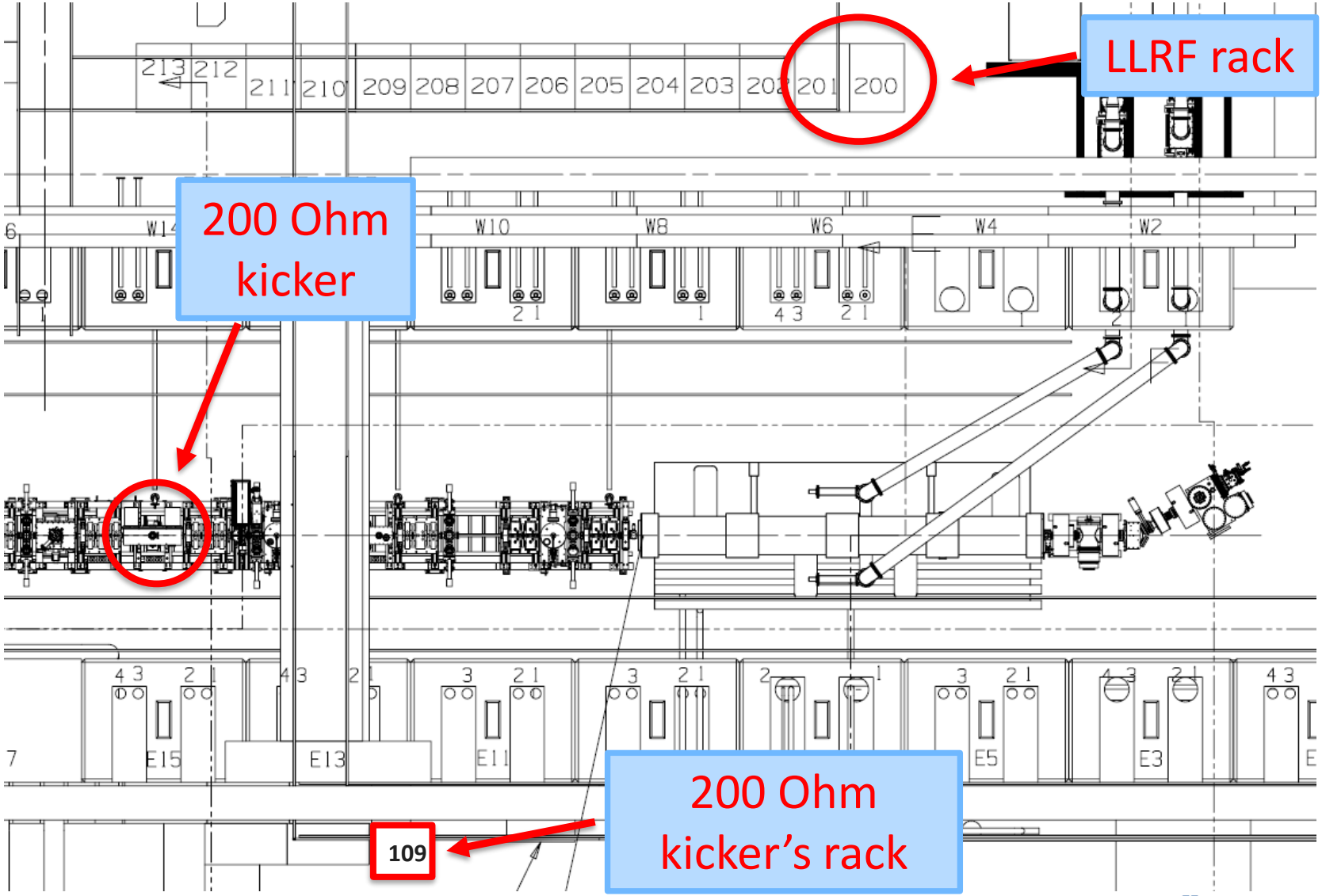
200 Ohm Kicker interconnections (cave's top view)



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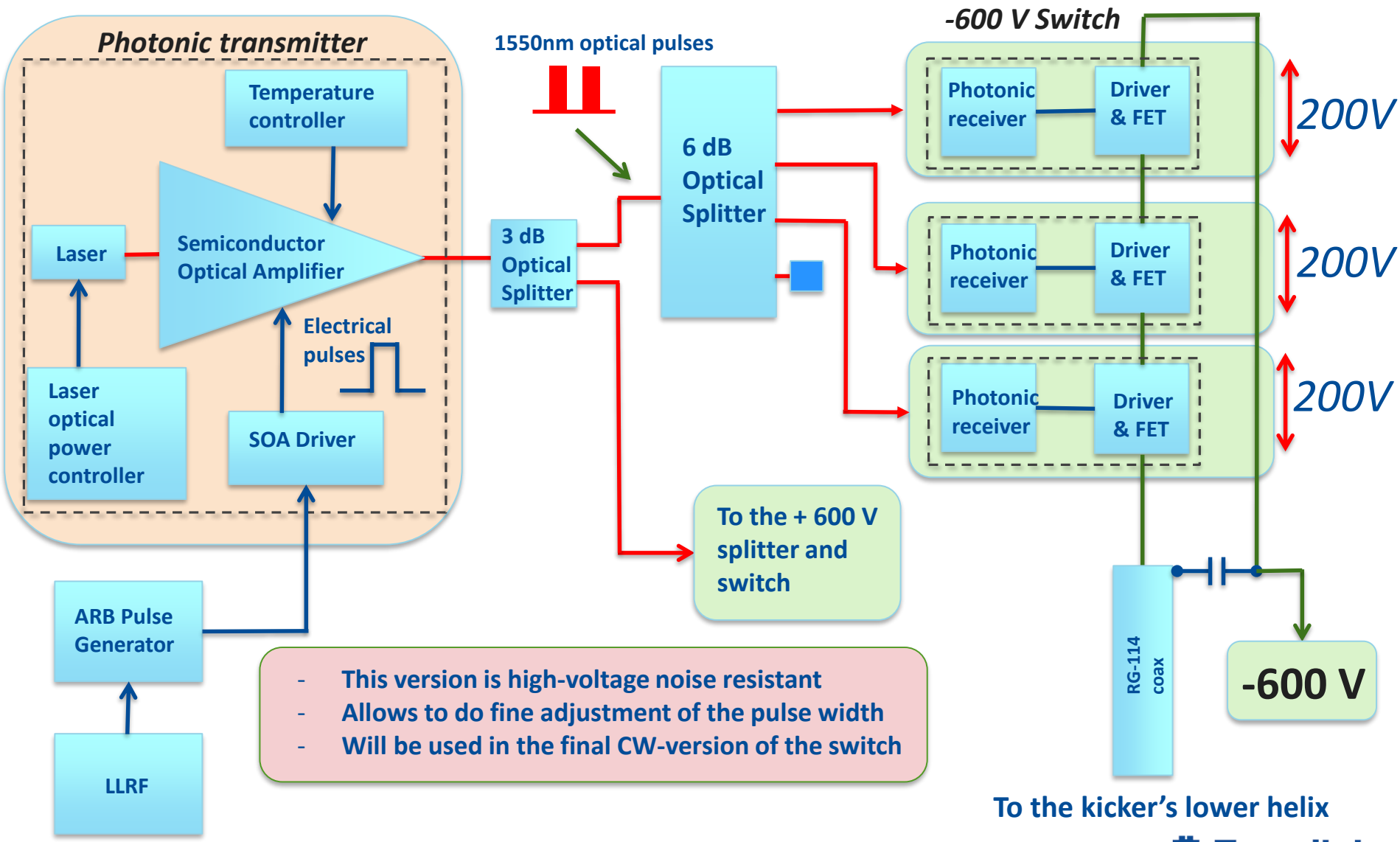
Block-diagram of the new version of kicker's driver



- This version is high-voltage noise resistant
- Allows to do fine adjustment of the pulse width
- Will be used in the final CW-version of the switch

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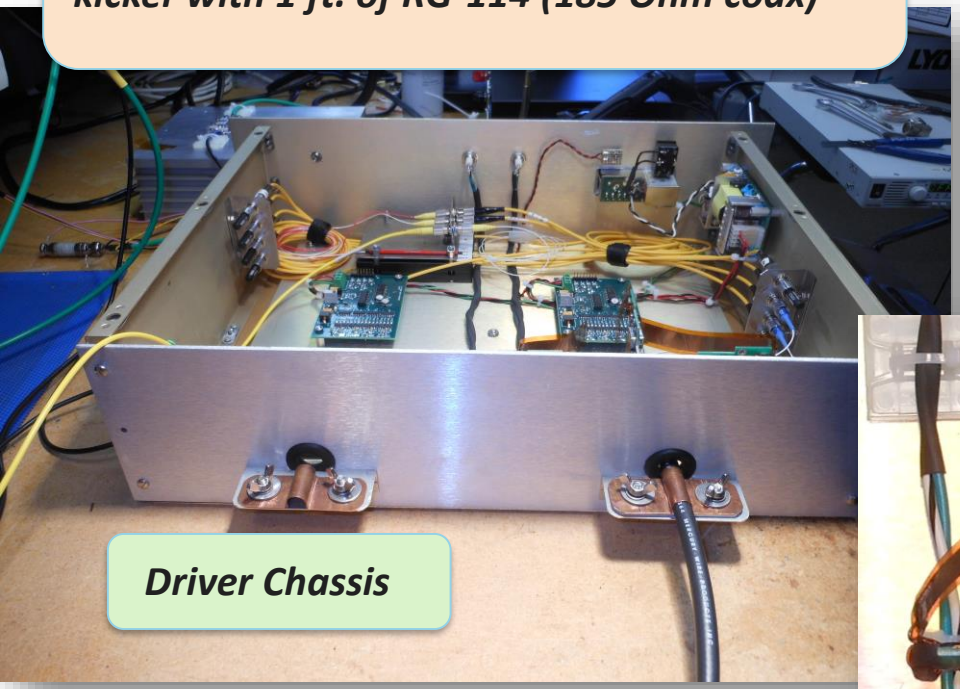
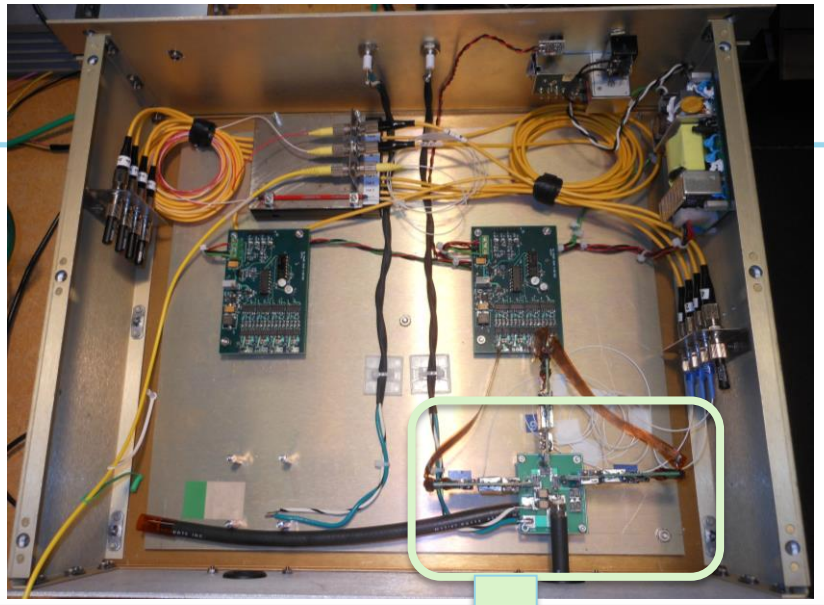
New hardware – The photonic transmitter & receivers

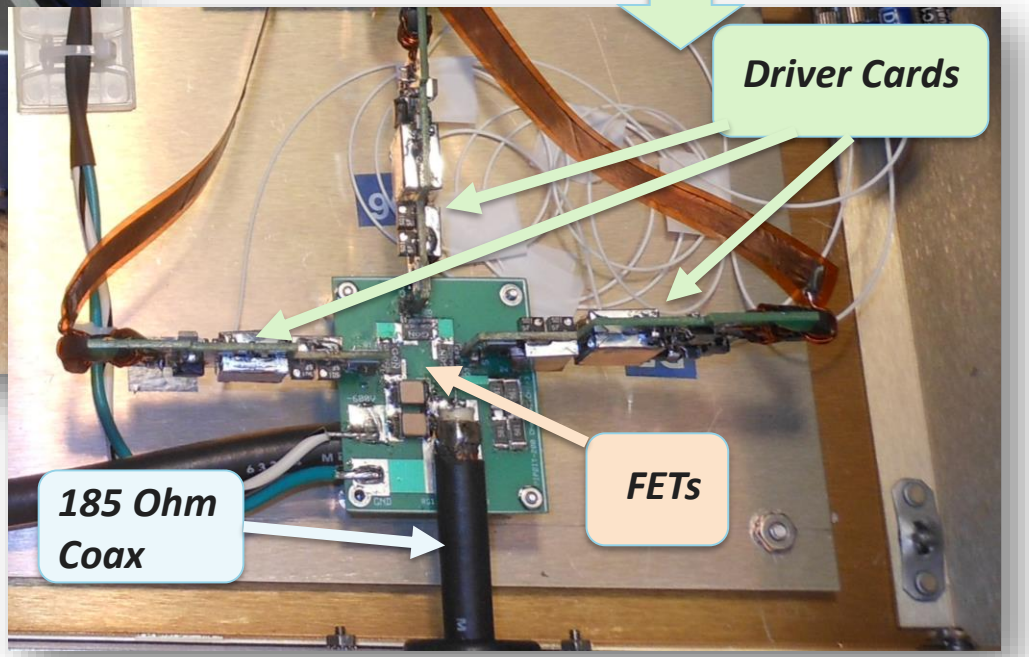
Photonic transmitter:

New hardware – The Switches

This Version has two switches +/- 600 Volts, in one chassis. Switches will be connected to the kicker with 1 ft. of RG-114 (185 Ohm coax)

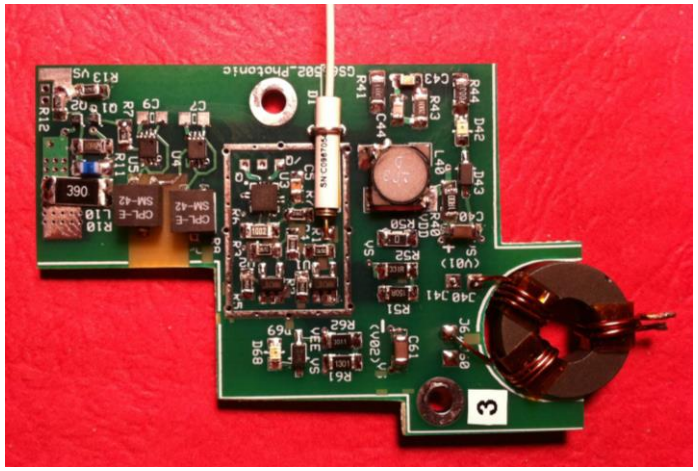


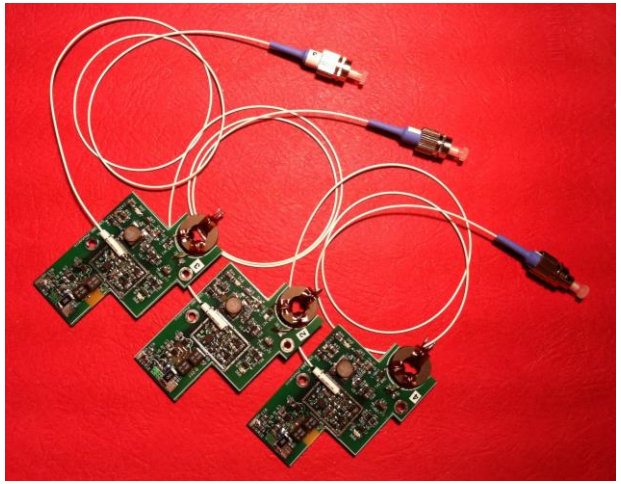




Updated driver and output connection

Photonic receivers (Drivers) :

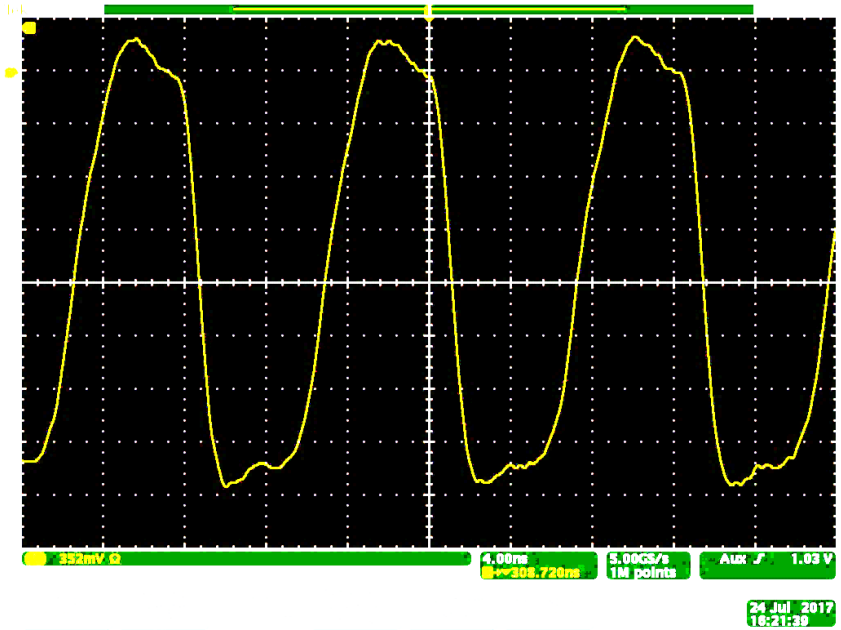




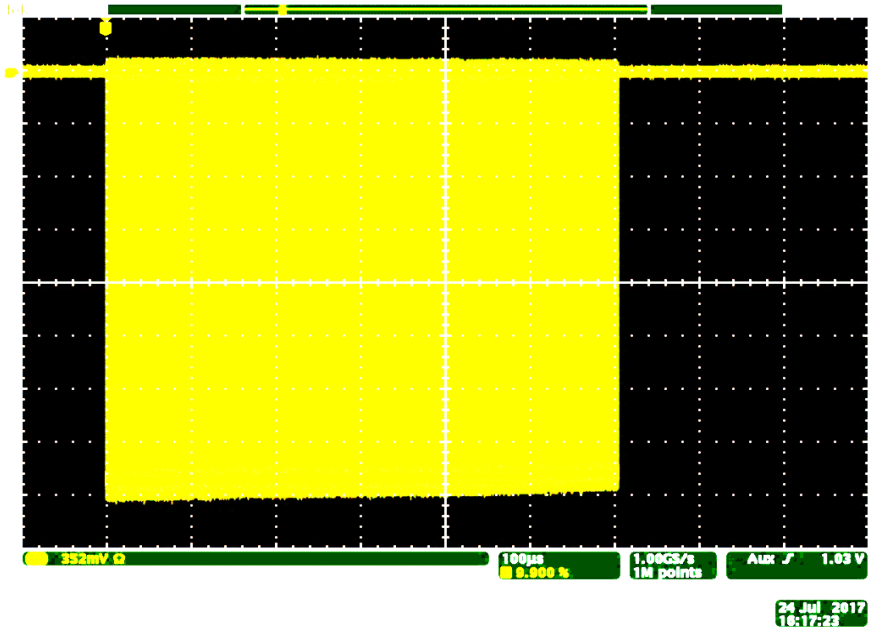
Feed-through prototype connection:

New switch performance:

Switching at 81 MHz, 10 us bursts:
600 Vp-p, 4 ns / div



Switching at 45 MHz average rate for 600 us:
600 Vp-p, 100 us / div



Path to a CW driver

- Test photonics version
  - Will be installed at PIP2-IT this summer
- Prototype a bipolar switch
  - Determine power losses to determine required cooling
- Mechanical design efforts
  - Design FET cooling hardware
  - Provide cooling water for 185 Ohm
- Prototype the “final” design

End